Weed Science, 50:607–610. 2002

Common waterhemp (*Amaranthus rudis*) interference in soybean

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Common waterhemp has become a problem weed species in Midwest soybean production. Determining the critical interference period after soybean and common waterhemp emergence is necessary for the implementation of weed control practices before soybean seed yield loss occurs. Field experiments were conducted during 1996, 1997, and 1998 to determine the influence of duration of common waterhemp interference on soybean seed yield. Removal of common waterhemp 2 wk after soybean unifoliolate leaf expansion resulted in soybean seed yield equivalent to a season-long weed-free control. Delaying common waterhemp removal until 4 wk after soybean unifoliolate leaf expansion resulted in decreased soybean seed yield. Allowing common waterhemp interference to persist 10 wk after soybean unifoliolate leaf expansion reduced soybean seed yield by an average of 43% over 3 yr. These results suggest that soybean producers should implement common waterhemp management strategies earlier than 4 wk after soybean unifoliolate leaf expansion in order to reduce the potential loss of soybean seed yield.

Nomenclature: Acifluorfen; sethoxydim; common waterhemp, *Amaranthus rudis* Sauer. AMATA; soybean, *Glycine max* (L.) Merr. 'Pioneer 9362', 'Pioneer 9363'.

Key words: Weed competition, interference removal timing.

Ten *Amaranthus* species occur as weeds across the Great Plains region, including the monoecious species redroot pigweed (*Amaranthus retroflexus* L.), smooth pigweed (*Amaranthus hybridus* L.), Powell amaranth (*Amaranthus powellii* S.Wats.), tumble pigweed (*Amaranthus albus* L.), prostrate pigweed (*Amaranthus blitoides* S.Wats.), and spiny amaranth (*Amaranthus spinosus* L.) and the dioecious species common waterhemp, tall waterhemp [*Amaranthus tuberculatus* (Moq.) J. D. Sauer], Palmer amaranth (*Amaranthus palmeri* S.Wats.), and sandhills amaranth (*Amaranthus arenicola* I. M. Johnst.) (Gleason and Cronquist 1991; Horak et al. 1994). Accurate identification of these *Amaranthus* species can be difficult during early vegetative development because many exhibit similar morphological characteristics (Ahrens et al. 1981; Sauer 1957). The morphological similarities of these *Amaranthus* species, coupled with the ability of some *Amaranthus* species to intercross and produce hybrids (Wetzel et al. 1999), has frequently resulted in incorrect identification. Much of the early literature may have incorrectly referred to several of these *Amaranthus* species as redroot or smooth pigweed (Wax 1995). Until recently, the most common *Amaranthus* species encountered in Midwest agronomic production systems was probably smooth pigweed (Wax 1995), but currently other *Amaranthus* species appear to be more prevalent.

Many taxonomic references recognize common and tall waterhemp as discrete species, although discernable morphological characteristics are based on diminutive pistillate characteristics (Gleason and Cronquist 1991; Horak et al. 1994). Wax (1995) suggests that common waterhemp is probably the dominant species in the western Midwest, whereas tall waterhemp occurs more frequently in the east. Identification of numerous waterhemp collections from Illinois indicated that common waterhemp was the most prevalent waterhemp species in Illinois (L. Wax, personal communication). Some have proposed that in lieu of two discrete species, waterhemp exists as a single, polymorphic species (Pratt and Owen 1999).

Common waterhemp infestations in Illinois agronomic production systems have become more frequent in recent years. Changes in agronomic production and weed management practices, differential susceptibility to herbicides, and the development of herbicide-resistant biotypes have contributed to the increased incidences and severity of common waterhemp infestations (Hager et al. 1997; Sprague et al. 1997; Wax 1995). Researchers in other states have also reported increased prevalence of this *Amaranthus* species (Hinz and Owen 1997; Horak and Peterson 1995). Much of the recent literature has focused on the incidences of herbicide resistance in common waterhemp populations, including resistance to acetolactate synthase–inhibiting and triazine herbicides (Anderson et al. 1996; Foes et al. 1998; Horak and Peterson 1995).

Germination and emergence of common waterhemp often extend further into the growing season than is common for other summer annual species. Hartzler et al. (1999) determined the emergence characteristics of common waterhemp, giant foxtail (*Setaria faberi* Herrm.), woolly cupgrass [*Erichloa villosa* (Thunb.) Villosa], and velvetleaf (*Abutilon theophrasti* Medicus) in central Iowa. Although the date of initial weed emergence varied among years, the emergence sequence among the four species was consistent across years. Woolly cupgrass and velvetleaf were the first species to emerge, whereas common waterhemp was consistently the last species to emerge, with initial emergence 5 to 25 d after velvetleaf. Additionally, common waterhemp had a longer emergence period than the other three species. Our personal observations from Illinois corn (*Zea mays* L.) and soybean production fields support the findings of R. G. Hartzler et al. (1999). The extended emergence of common waterhemp can present significant management difficulties for soybean producers, especially in production systems that rely exclusively on herbicides for weed control (Hager et al. 1997). Soil-applied herbicides may not have sufficient soil residual activity to control late-emerging flushes of common waterhemp. Conversely, certain postemergence (POST) herbicides can control common waterhemp present at the time of application but not plants that emerge after application.

Interference of several *Amaranthus* species with soybean has been previously reported. Moolani et al. (1964) reported that over a 3-yr period, the average soybean yield loss was 55% because of competition with smooth pigweed. Nave and Wax (1971) found that soybean yield was reduced 25 to 30% with 1 smooth pigweed 0.3 m^{-1} in 76-cm-spaced soybean rows. Shurtleff and Coble (1985) reported a 22% soybean seed yield reduction from redroot pigweed interference at a density of 16 plants 10 m^{-1} of row. Klingaman and Oliver (1994) found soybean seed yield was reduced between 17 and 68% from Palmer amaranth interference at densities between 0.33 and 10 plants m^{-1} of row.

The interference potential of common or tall waterhemp has not been as extensively reported in the literature as has been the interference potential of other *Amaranthus* species. Feltner et al. (1968) examined the competitive influence of tall waterhemp on sorghum [*Sorghum bicolor* (L.) Moench] and found fodder and grain yields generally decreased as tall waterhemp density or duration of competition increased. The magnitude of sorghum response to tall waterhemp competition varied across years, which the authors attributed to enhanced nitrogen fertility and more abundant rainfall in 1965 compared with 1964. Bensch et al. (2000) compared the competitive influence of redroot pigweed, Palmer amaranth, and common waterhemp on soybean seed yield and reported that common waterhemp reduced soybean seed yield more than redroot pigweed but less than Palmer amaranth.

Illinois soybean producers frequently rely on POST herbicides to control common waterhemp and other *Amaranthus* species. Successful implementation of integrated management systems for common waterhemp requires knowledge of the duration of interference that soybean can tolerate without seed yield loss. Growers could utilize this information to time their management strategies appropriately to eliminate common waterhemp interference before soybean seed yield is reduced. The objective of this research was to determine the duration of early-season common waterhemp interference that soybean could tolerate before soybean seed yield was reduced.

Materials and Methods

Site Description and Experiment Establishment

Field experiments were conducted in 1996, 1997, and 1998 at the Crop Sciences Research and Education Center in Urbana, Illinois, on a Drummer silty clay loam soil (fine-silty, mixed, superactive, mesic, Typic Endoaquolls). Each year, the experimental area was chisel plowed in the fall and field cultivated twice in the spring before soybean planting. Plots were 3 by 7.6 m in 1996 and 1998 and 3 by 8.5 m in 1997 and consisted of 4 soybean rows spaced 76 cm apart. Pioneer 9362 soybean was planted on June 5, 1996, and Pioneer 9363 soybean was planted on May 15, 1997, and May 22, 1998, at a rate of 395,000 seeds ha^{-1}. Each year, common waterhemp seed[1] was spread across the experimental area with a hand-held seed spreader 2 to 3 wk before and immediately after soybean planting to supplement the indigenous waterhemp population. To simulate a soybean production situation, no attempt was made to confine common waterhemp to a specific distance from or within the soybean rows or to establish absolute densities. Throughout the growing season, all plots were hand weeded to remove other broadleaf species. In 1997 sethoxydim was applied at 210 g ai ha^{-1} plus 0.5 % (v/v) crop oil concentrate[2] to control annual grass species. In 1996 and 1998 grass populations were low enough to allow removal by hand weeding. Weed-free plots were maintained with a preemergence (PRE) application of metolachlor plus metribuzin (2.2 and 0.42 kg ai ha^{-1}, respectively) supplemented by weekly hand weeding. All herbicides were applied with a backpack CO_2 sprayer equipped with either XR11003[3] (PRE applications) or XR8002 (POST applications) flat fan spray tips spaced 51 cm apart on a 3-m boom at 187 L ha^{-1} and 276 kPa. At full maturity, the middle two soybean rows of each plot were mechanically harvested and seed yields adjusted to 13% moisture.

Common Waterhemp Early-Season Interference Duration

Common waterhemp was removed from the appropriate plots 2, 4, 6, 8, and 10 wk after soybean unifoliolate leaf expansion. Soybean unifoliolate leaf expansion was utilized as the benchmark in lieu of weeks after soybean planting or emergence because no common waterhemp had emerged before soybean unifoliolate expansion. Common waterhemp density was determined at each interference removal timing by counting the total number of common waterhemp plants present within a 1-m^2 quadrat placed between the two middle soybean rows. After the determination of density at each interference removal timing, common waterhemp plants within the quadrat were harvested and oven dried, and dry weights recorded. To simulate typical soybean production, acifluorfen was applied POST at 280 g ai ha^{-1} plus 0.25% (v/v) nonionic surfactant[4] (NIS) to remove common waterhemp at each interference removal timing previously described. Two weeks after each POST acifluorfen application, all the remaining common waterhemp plants were removed by hand, and plots were subsequently kept weed free for the remainder of the growing season. The influence of the duration of common waterhemp interference on soybean seed yield was determined by comparing soybean seed yields from each interference duration interval with that of a season-long weed-free control. The influence of acifluorfen on soybean seed yield was determined by applying 280 g ai ha^{-1} acifluorfen plus 0.25 percent (v/v) NIS to weed-free soybean plots at each interference removal timing. Single degree of freedom contrasts were used to compare soybean seed yields from these plots with that of the season-long weed-free control.

Statistical Analysis

The experimental design was a randomized complete block with four replications. All data were analyzed using the SAS MIXED procedure (SAS 2000). Each year was con-

TABLE 1. Common waterhemp (*Amaranthus rudis*) density and dry weights for each early-season interference removal interval, 1996, 1997, and 1998, in Urbana, IL.

Common waterhemp removal timing[a]	1996		1997		1998	
	Density[b]	Dry weight	Density[b]	Dry weight	Density[b]	Dry weight
	plants $ha^{-1} \times 10^4$	kg ha^{-1}	plants $ha^{-1} \times 10^4$	kg ha^{-1}	plants $ha^{-1} \times 10^4$	kg ha^{-1}
Weed free	—	—	—	—	—	—
2	627 ± 94	140 ± 24	1315 ± 79	150 ± 16	235 ± 33	35 ± 5
4	756 ± 73	940 ± 85	1057 ± 119	1060 ± 157	280 ± 32	380 ± 48
6	554 ± 75	1940 ± 214	621 ± 75	1100 ± 225	164 ± 7	2200 ± 558
8	239 ± 29	3300 ± 362	171 ± 15	1300 ± 268	104 ± 8	1300 ± 108
10	362 ± 78	5790 ± 185	146 ± 15	820 ± 206	89 ± 8	3500 ± 765

[a] Removal timings are weeks after soybean (*Glycine max*) unifoliolate expansion.
[b] Density and dry weights were collected in a 1-m^2 area of each plot. Mean values are reported ± standard errors.

sidered an environment, and environments, replications (nested within environments), and the interaction (treatment by environment) were considered as random effects, as suggested by Carmer et al. (1989); therefore, their effects were evaluated by their variance components. All other variables were considered to be fixed effects. Considering environments to be random permits inferences about the treatments to be made over a range of environments (Carmer et al. 1989). Individual treatment (duration of interference) differences were determined using Fisher's protected LSD ($P = 0.05$). Regression analysis was performed to describe the relationship between soybean seed yield and duration of common waterhemp interference using the REG PROCEDURE of SAS (SAS 2000). Linear and quadratic equations were tested to describe the relationship between the duration of common waterhemp interference and soybean seed yield. A quadratic regression equation did not significantly improve the model over a linear equation.

Results and Discussion

Influence of Acifluorfen on Soybean Seed Yield

Acifluorfen caused minor soybean injury, consisting primarily of leaf necrosis (data not shown). Seed yields of soybean plots maintained weed free and treated POST with acifluorfen at each common waterhemp interference removal timing were compared with the yield from a season-long weed-free control (not treated with acifluorfen POST) to determine if the herbicide influenced soybean seed yield. No significant soybean seed yield differences were observed; thus, any soybean seed yield differences observed at various common waterhemp interference removal times were not attributable to acifluorfen injury but were attributed to common waterhemp interference.

Critical Period of Common Waterhemp Early-Season Interference

Common waterhemp densities ranged from 239 to 756, 146 to 1,315, and 89 to 280 plants m^{-2} in 1996, 1997, and 1998, respectively (Table 1). The highest common waterhemp density was recorded at the 2- or 4-wk removal interval each year. Intra- and interspecific interference reduced common waterhemp densities after the 4-wk removal interval, but densities remained high enough to adversely influence soybean seed yield 10 wk after soybean unifoliolate leaf expansion. Common waterhemp dry weight values increased at each successive removal timing, except dry weight values which declined between the 8- and 10-wk removal times in 1997 and between the 6- and 8-wk removal times in 1998 (Table 1).

Soybean seed yield from season-long weed-free plots was 3,410 kg ha^{-1} (Figure 1; Table 2). Removal of common

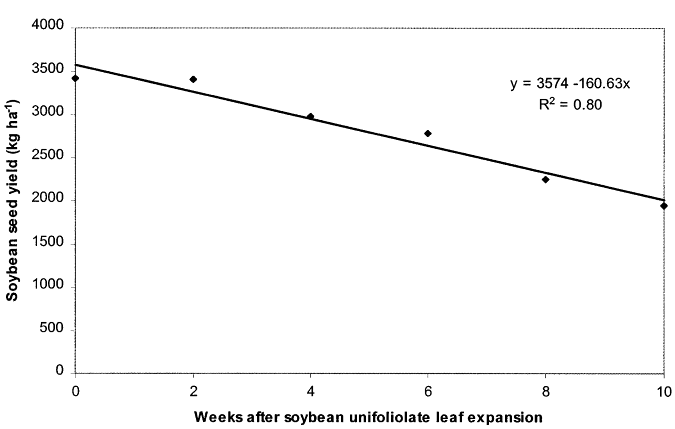

FIGURE 1. Linear regression of soybean (*Glycine max*) seed yield relative to time of common waterhemp (*Amaranthus rudis*) interference removal in 1996, 1997, and 1998 at Urbana, IL.

TABLE 2. Soybean (*Glycine max*) seed yields as influenced by early-season common waterhemp (*Amaranthus rudis*) interference averaged across three environments.

Common waterhemp removal timing[a]	Soybean seed yield	Soybean seed yield reduction[b]
	kg ha^{-1}	%
Weed free	3,410	—
2	3,400	1
4	2,970	13
6	2,780	19
8	2,250	34
10	1,950	43
$LSD_{0.05}$	290	8

[a] Removal timings are weeks after soybean unifoliolate expansion.
[b] Percent soybean yield reduction calculated by the equation 1-(yield at removal timing/yield of weed free) × 100.

waterhemp interference 2 wk after soybean unifoliolate leaf expansion resulted in seed yields equivalent to the season-long weed-free control. However, when common waterhemp interference was allowed to continue 4 wk or longer after soybean unifoliolate leaf expansion, soybean seed yield was reduced. These results suggest that when soybean is grown in 76-cm row spacings, producers should implement common waterhemp control measures between 2 and 4 wk after soybean unifoliolate leaf expansion to reduce potential soybean seed yield loss.

Full-Season Common Waterhemp Interference

Common waterhemp interference up to 10 wk after soybean unifoliolate leaf expansion reduced soybean seed yield 43% compared with the season-long weed-free control (Table 2). These results are similar to the soybean yield loss reported by Nave and Wax (1971) for smooth pigweed interference at a density of 1 plant 0.3 m^{-1} in 76-cm-spaced soybean rows and to the soybean yield loss from redroot pigweed interference at a density of 16 plants 10 m^{-1} of row reported by Shurtleff and Coble (1985). In these previous studies, however, pigweed populations were thinned to defined densities that were lower than the common waterhemp densities reported here, and pigweed plants were confined to within the crop row to facilitate interrow crop cultivation. Current soybean production in Illinois frequently does not include soil-applied residual herbicides or interrow cultivation for weed management, thereby placing additional emphasis on POST weed control. Because of this, common waterhemp densities in soybean production fields before POST herbicide application frequently approximate the densities obtained in this research.

Common waterhemp has become one of the most problematic *Amaranthus* species with which soybean producers must contend. Results of this research indicate that common waterhemp interference can reduce soybean yield up to 43%, which is similar to the soybean yield losses reported for other *Amaranthus* species (Nave and Wax 1971; Shurtleff and Coble 1985). Soybean producers who rely on POST herbicides to control common waterhemp should apply them between 2 and 4 wk after soybean unifoliolate leaf expansion to reduce the potential for soybean seed yield loss.

Sources of Materials

[1] Azlin Seed Service, 112 Lilac Drive, P.O. Box 914, Leland, MS 38756.

[2] Prime Oil crop oil concentrate, Terra Industries Inc., 600 Fourth Street, P.O. Box 6000, Sioux City, IA 51101.

[3] XR11003, XR8002 Teejet spray nozzles, Spraying Systems Co., North Avenue at Schmale Road, P.O. Box 7900, Wheaton, IL 60189.

[4] Activate Plus nonionic surfactant, Terra Industries Inc., 600 Fourth Street, P.O. Box 6000, Sioux City, IA 51101.

Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the United States Department of Agriculture or the University of Illinois.

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Received June 12, 2001, and approved March 1, 2002.